28573
new 79-01

COMPLIMENTARY COPY
*Please Credit Ontario Hydro Research if Reproduced in Whole or in Part.*

ontario hydro
research division

# ACOUSTICALLY OBSERVED FISH DISTRIBUTION AND ABUNDANCE NEAR THE SITE OF DARLINGTON GS

Report No 82-471-K

H. Balesic
Biologist - Fish Behaviour
Biological Research Section
Chemical Research Department

## ABSTRACT

Acoustic fish census data collected between July 1978 and June 1979 near Darlington was re-examined to allow consideration of potential fish entrapment by a submerged intake. Over the year highest densities were found at depths of 4-8 m (1100-1300/10,000 $m^3$). Beyond the 8 m contour densities were highest within 1 m of bottom and decreased with increasing depth contours. Alewife and rainbow smelt contributed virtually all the acoustically observed fish.



| job | file | date | report no |
|---|---|---|---|
| 740634-314-492 | 837.315 | December 31, 1982 | 82-471-K |

TABLE OF CONTENTS


| | Page |
|---|---|
| INTRODUCTION | 1 |
| METHODS | 1 |
| Acoustic Fish Census | 1 |
| Sample Design and Analysis | 3 |
| RESULTS AND DISCUSSION | 4 |
| Temporal Trends in Abundance | 4 |
| Fish Distribution During Spring-Summer | 5 |
| Fish Distribution During Fall-Winter | 8 |
| Yearly Average Distribution | 10 |
| Potential Fish Losses at Submerged Intakes | 12 |
| SUMMARY | 13 |
| REFERENCES | 14 |
| APPENDICES | 15 |
| DISTRIBUTION | |

## FIGURES


| | | Page |
|---|---|---|
| 1. | SELECTED ACOUSTIC TRANSECTS IN THE VICINITY OF DARLINGTON GS | 2 |
| 2. | VERTICAL DISTRIBUTION OF FISH IN THE VICINTIY OF DARLINGTON GS: SPRING SUMMER | 6 |
| 3. | VERTICAL DISTRIBUTION OF FISH IN THE VICINITY OF DARLINGTON GS: FALL WINTER | 9 |
| 4. | FISH DENSITY IN THE VICINITY OF DARLINGTON GS; YEARLY AVERAGE | 11 |

## TABLES


| | | Page |
|---|---|---|
| 1. | ACOUSTIC SAMPLES INCLUDED IN ANALYSIS | 3 |
| 2. | MEAN FISH DENSITIES PER HECTARE IN 2 KM GRID SAMPLES | 4 |
| 3. | SPECIES COMPOSITION IN NETTING CARRIED OUT IN CONJUNCTION WITH ACOUSTIC CENSUS: SPRING-SUMMER | 7 |
| 4. | SPECIES COMPOSITION IN NETTING CARRIED OUT IN CONJUNCTION WITH ACOUSTIC CENSUS: FALL-WINTER | 10 |

28572
new 79-01

ontario hydro
research division

To Mr. F.J. Kee
Director of Research

# ACOUSTICALLY OBSERVED FISH DISTRIBUTION AND ABUNDANCE NEAR THE SITE OF DARLINGTON GS

## INTRODUCTION

Ontario Hydro requires fish distribution and abundance data for the assessment of potential fish entrapment so that siting and design of intakes with minimal impact can be selected.

Acoustic fish census (quantification of fish targets obtained by echo sounding) offers major advantages in assessment of fish abundance. It allows the generation of a picture of the in situ distribution of fish over a large area and through the water column at essentially one point in time. Accordingly, acoustic fish census was carried out near the Darlington GS site in summer, fall and early winter, 1978 and spring 1979 as part of E15/E16 site studies (Ontario Hydro Research Division Report No 80-387-K; site has been suspended) and a fish distribution study in the nearshore zone of Lake Ontario (Ontario Hydro Research Division Reports No 79-363-K, No 79-434-K and No 80-197-K). One 2 km x 2 km sampling grid was located off the Darlington GS site and a second from the St. Mary's Cement plant to Port Darlington (Figure 1). In previous reports, horizontal and vertical distribution were described for each of the samples collected. However, vertical resolution was coarse, and a year-round assessment of abundance relative to depth and distance offshore was not provided. Here the data was re-examined to correct these deficiencies and improve its utility for assessment of numbers of fish vulnerable to intake entrapment.

## METHODS

### Acoustic Fish Census

Acoustic fish census was conducted with a high resolution echo sounder interfaced with an echo analysis system. Data were subsequently converted to fish densities per volume (10,000 $m^3$) and area (hectare). Fish species composition was determined by gill nets set inshore at approximately 5 m depth, and offshore at approximately 20 m depth (Figure 1). At Darlington a trawl was also operated just off bottom at 12-15 m depth. Detailed descriptions of apparatus and methodology are given in Ontario Hydro Research Division Report No 79-363-K and No 80-197-K.



82-471

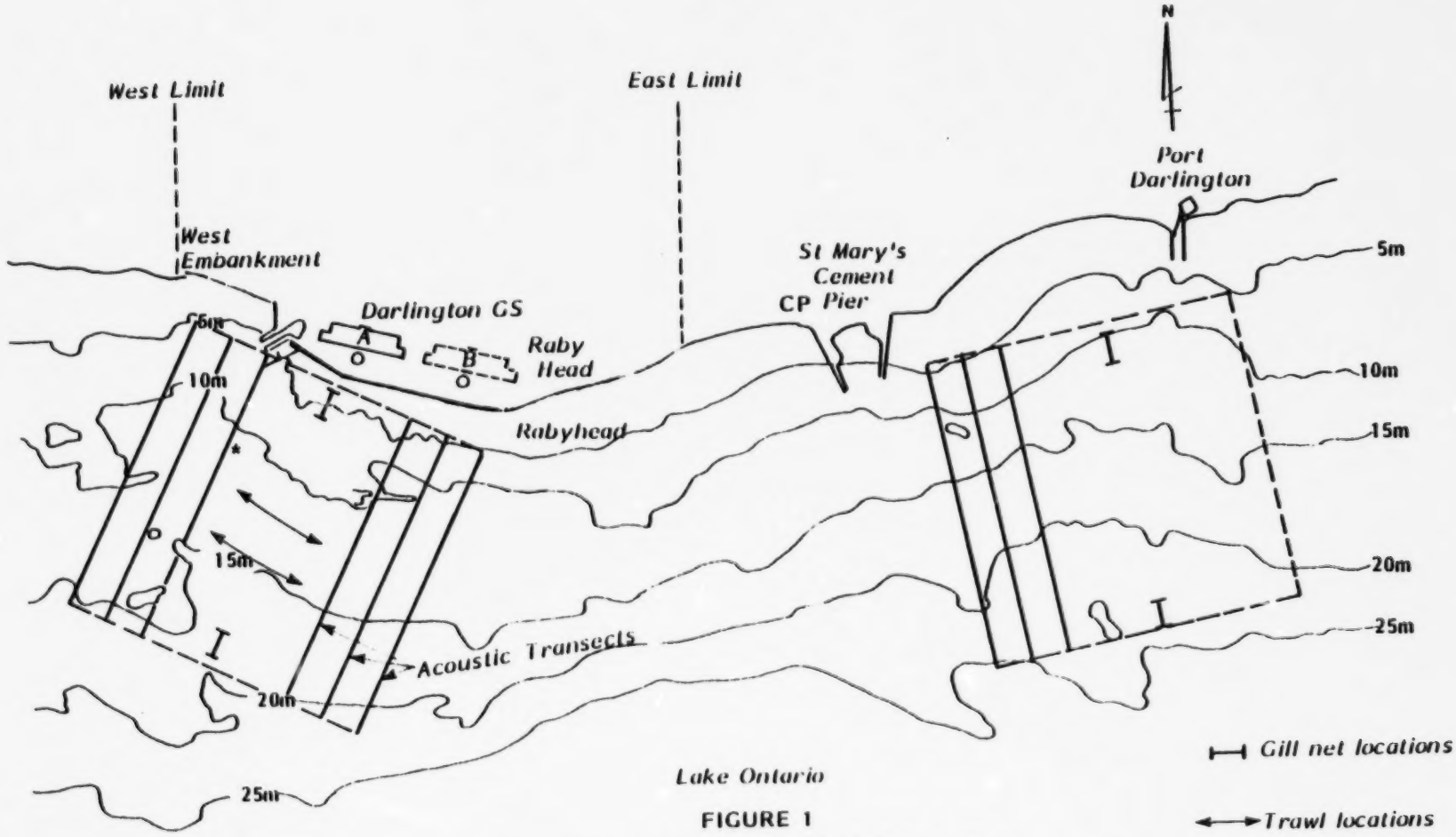



FIGURE 1

SELECTED ACOUSTIC TRANSECTS IN THE VICINITY OF DARLINGTON GS

150165 RD

## Sample Design and Analysis

Daytime acoustic grid samples were taken at Darlington GS during six sampling periods and at Port Darlington during five periods. Night samples were taken only at Darlington GS during four periods. Sampling dates are given in Table 1. Complete grid samples consisted of nine parallel transects approximately perpendicular to the shoreline. Three segments of 3 transects each were selected for analysis (Figure 1). These were opposite the West Embankment and Raby Head from the Darlington GS grid, and opposite the St. Lawrence Cement plant in the Port Darlington grid.

Data were logged such that individual data cells were 4 m in depth referenced by distance from the transducer. This gave only a coarse indication of density relative to the bottom. Therefore, a system was devised by which the available data could provide fish densities in 1 m increments from the bottom upwards.

TABLE 1. ACOUSTIC SAMPLES INCLUDED IN ANALYSIS

| | SPRING - SUMMER | | FALL - WINTER | |
|---|---|---|---|---|
| | DAY | NIGHT | DAY | NIGHT |
| DARLINGTON | MAY 23, 1979 | MAY 23 | NOV 20, 1978 | NOV 20, 1979 |
| | JULY 9, 1979 | JULY 11 | DEC 19, 1978 | |
| | AUG 23, 1978 | - | | |
| | SEPT 28, 1978 | SEPT 28,1978 | | |
| PORT DARLINGTON | MAY 22, 1979 | | NOV 16, 1978 | |
| | JULY 6, 1979 | | | |
| | AUG 3, 1978 | | | |
| | OCT 10, 1978 | | | |

Within a season and time of day densities relative to the distance from the bottom were estimated over 4 m bottom depth increments corresponding to the automatic depth sorting ranges. Typically a number of data logging intervals with the bottom at various depths within the 4 m range were obtained. This allowed construction of a plot of the contribution of various-sized portions of the water column to total density in the water column. From this plot the average density/10,000 $m^3$ at 1 m increments above the bottom was estimated. An example of procedure is provided in Appendix I.

## RESULTS AND DISCUSSION

### Temporal Trends in Abundance

An overview of seasonal changes in abundance can be obtained from the mean densities in the 15 two km grid samples (Table 2). Highest densities were found in May (5725 fish/hectare by day off Darlington GS) and August. This appeared to reflect periods of high abundance of alewife in the acoustically sampled strata from 4 to 20 m depth (Ontario Hydro Research Division Report No 80-197-K). In July lower abundance was probably the result of alewife moving into shallower depths, rather than leaving the nearshore zone. It was suggested that similar movements accounted for the lower abundance by night in May and July, and this was supported by large catches in inshore near-surface gill nets. Densities obtained during mid-October to December were consistently low (below 400 fish/hectare).

TABLE 2

MEAN FISH DENSITIES (NO/HECTARE)
IN 2 KM GRID SAMPLES

| | Month | Darlington GS | | Port Darlington |
|---|---|---|---|---|
| | | Day | Night | Day |
| Spring-Summer | May | 5425 | 1835 | 1560 |
| | July | 1565 | 922 | 1073 |
| | Aug | 2385 | | 2360 |
| | Sept/Oct | 843 | 1855 | 571 |
| Fall-Winter | Nov | 311 | 367 | 157 |
| | Dec | 345 | | |

## Fish Distribution During Spring-Summer

By day densities within 1 m of bottom were generally more than twice as high as those over 2 m from bottom (Figure 2, Appendix I). For example, in the area of the proposed Darlington GS A intake off the West Embankment (bottom depth range 8-12 m) mean density was 4123 fish/$m^3$ within 1 m of bottom but declined to 434/10,000 $m^3$ at 2-3 m from bottom.

Both vertical and onshore-offshore distribution of fish were similar at the West Embankment and Raby Head. Port Darlington was broadly similar to the two Darlington GS sites, although inshore densities (8-12 m depth) were somewhat lower, and greater midwater abundance was evident in offshore waters.

Off both the West Embankment and Raby Head near-bottom densities were substantially higher at 8-12 m depths than further offshore. At 8-12 m densities within 2 m of bottom ranged from 650-4100 fish/hectare, while at greater depths densities within 2 m of bottom ranged from 180 to 920 fish/hectare.

At night acoustic sampling was conducted only at Darlington GS. Fish densities were again generally highest near bottom, but the degree of concentration was not nearly as great. A maximum of 899 fish/10,000 $m^3$ was found within 1 m of the bottom at 8-12 m depth off the West Embankment. At depths to 16 m moderate numbers of fish were scattered from bottom to 4 m (minimum depth for echo processing). Beyond the 16 m depth, fish were concentrated into two bands: a relatively narrow band on bottom and a broader, more diffuse band in the mid-to-upper portion of the water column.

Gill netting and trawling results indicated that alewife (Alosa pseudoharengus) and rainbow smelt (Osmerus mordax) accounted for virtually all of the observed fish echoes (Table 3). Both are pelagic species which are seasonally abundant in nearshore waters.

Association of netting results and echo records indicated that by day alewife generally formed well-spaced schools which were easily resolved into individuals on the graphic record. At moderate depths, these schools were of varying sizes from small to very large and extended from bottom to 3-4 m off bottom. In deeper water the schools were generally not large and were more often off the bottom.

Rainbow smelt tended to form schools which were more densely spaced and more closely associated with the bottom than those of alewife. A survey of daytime schooling patterns (from the graphic record) indicated that alewife predominated to a depth of approximately 12 m, with smelt becoming progressively more important at greater depths. This was supported by netting, where alewife dominated inshore gill net catches while smelt dominated the smaller offshore gill net and trawl catches.

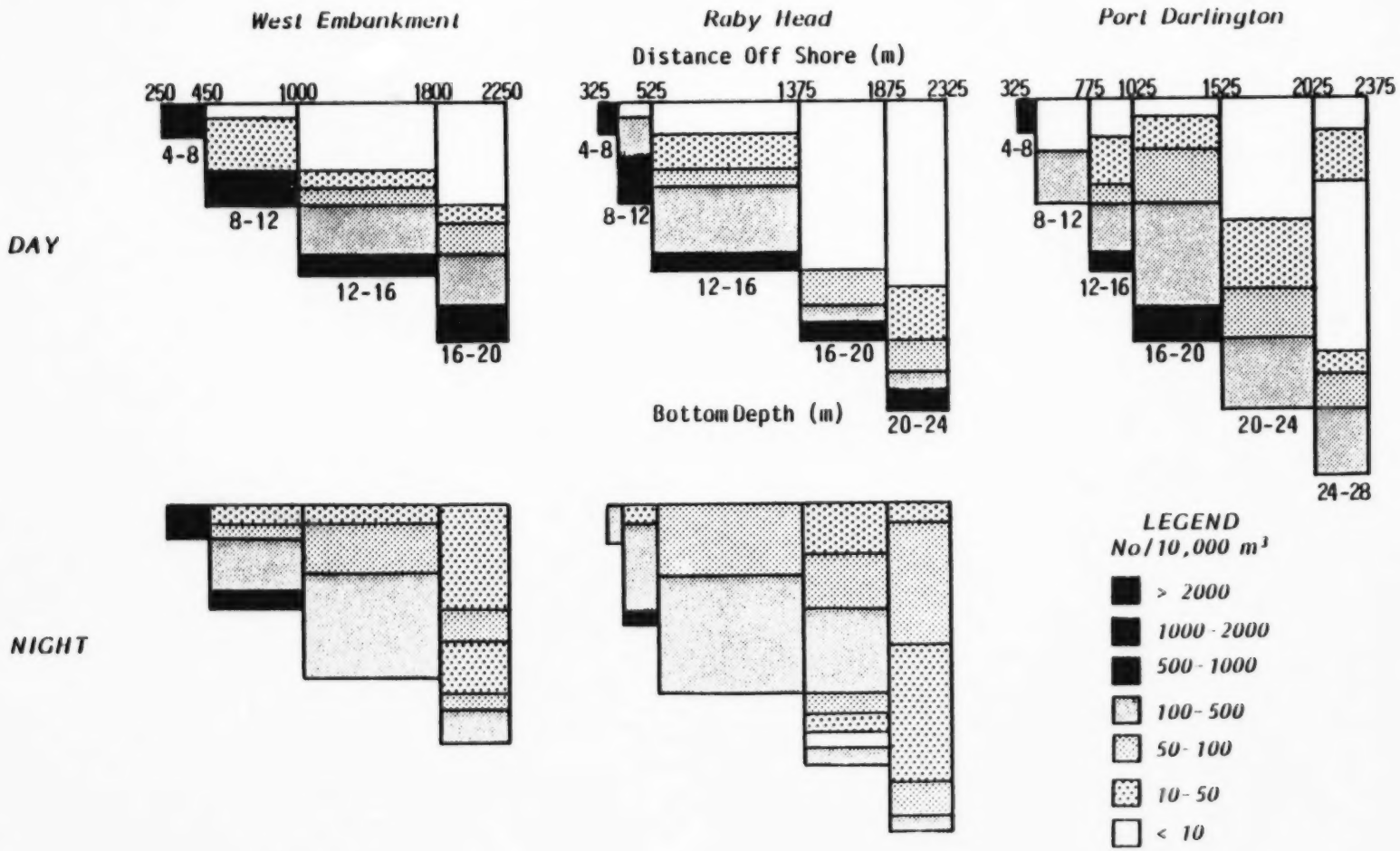



FIGURE 2

VERTICAL DISTRIBUTION OF FISH IN THE VICINITY OF DARLINGTON GS: SPRING - SUMMER

TABLE 3

SPECIES COMPOSITION IN NETTING CARRIED OUT IN CONJUNCTION WITH ACOUSTIC CENSUS: SPRING-SUMMER

| | Darlington GS | | | | Port Darlington | | | |
|---|---|---|---|---|---|---|---|---|
| | Inshore[1] | | Offshore[2] | | Inshore[1] | | Offshore[3] | |
| | No | % | No | % | No | % | No | % |
| DAY | | | | | | | | |
| Alewife | 735 | 93 | 44 | 22 | 55 | 76 | 176 | 69 |
| Rainbow Smelt | 52 | 7 | 159 | 78 | 13 | 18 | 76 | 29 |
| White Sucker | 2 | | | | 1 | 1 | | |
| Rainbow Trout | 1 | | | | 1 | 1 | | |
| Yellow Perch | | | | | | | | |
| Round Whitefish | | | | | 2 | 2 | 4 | 2 |
| TOTAL | 790 | | 203 | | 72 | | 256 | |
| NIGHT | | | | | | | | |
| Alewife | 1332 | 82 | 1 | 3 | | | | |
| Rainbow Smelt | 264 | 15 | 33 | 89 | | | | |
| White Sucker | 13 | 1 | | | | | | |
| Brown Bullhead | 8 | 1 | | | | | | |
| White Perch | 1 | | | | | | | |
| Round Whitefish | | | 2 | 8 | | | | |
| TOTAL | 1618 | | 37 | | | | | |

1 Includes surface and bottom gill nets in 4-7 m depth

2 Includes bottom gill nets at 20 m depth, trawl at 11-15 m

3 Bottom gill nets only

However, alewife were probably under-represented in offshore gill net catches due to their tendency to be less closely associated with the bottom at greater depths.

By night fish dispersed upwards and, to some extent, towards shore. The substantial contribution of smelt to inshore gill net catches at night indicated inshore movement of that species. Alewife displayed the greater upward movement, as they tended to be concentrated in surface inshore gill nets (1-2 m depth) and were only rarely taken in offshore bottom nets. Although direct evidence is lacking, it appears that in deeper water the midwater bands of concentration represent alewife, while those adjoining the bottom represent smelt.

The relative contribution of smelt and alewife to overall fish abundance in the nearshore area varied considerably from sample to sample. Over the entire spring-summer period alewife were evidently the most abundant fish at both Darlington and Port Darlington. Smelt may have assumed a greater importance at Port Darlington, based on more consistent observation of extensive (presumed) smelt schools.

Fish Distribution During Fall-Winter

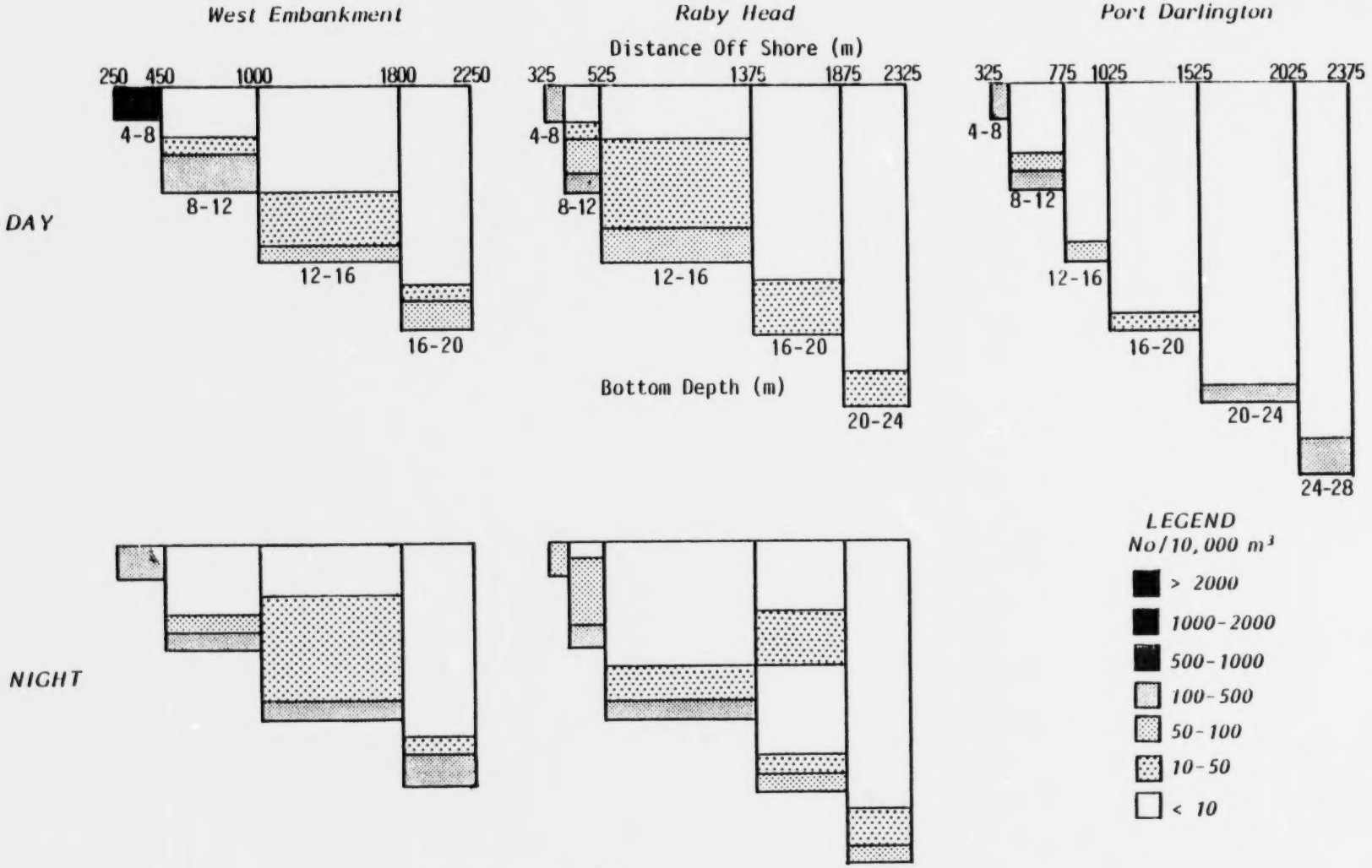
By day vertical distribution of fish resembled that seen earlier in the year, although densities were lower, and fish were restricted to bottom to a greater extent (Figure 3).

Highest densities were observed within 1 m of bottom, with a maximum of 382 fish/10,000 $m^3$ at 8-12 m bottom depth at the West Embankment. At that location density declined sharply quite close to the bottom, being only 13 fish/10,000 $m^3$ at 2-3 m off bottom. Port Darlington, with the lowest abundance, had an even more restricted vertical distribution.

Near-bottom fish densities generally decreased with increasing depth at all three sites. However, secondary concentrations were seen offshore (below 20 m) in the single Port Darlington sample.

At night fish were again concentrated near bottom. Few fish were found scattered in midwater, which was quite unlike the spring-summer distribution.

In November and December the typical echo aggregations, attributed to smelt and alewife earlier in the year, were lacking and net catches were too small to show species composition (Table 4). However, supporting information was available from intensive gill netting conducted in the vicinity of Darlington GS in 1977 (Ontario Hydro Research Division Report No 78-48-K). Round Whitefish (Prosopium williamsoni) was the most abundant species contributing up to 50% of the catch in 1978 and 38% in 1977. They obviously made an important contribution to total fish density during late fall. Although not well represented in net catches, alewife may have been at least equally abundant. The




150167 RD

FIGURE 3

VERTICAL DISTRIBUTION OF FISH IN THE VICINITY OF DARLINGTON GS: FALL - WINTER

TABLE 4

SPECIES COMPOSITION IN NETTING CARRIED OUT IN CONJUNCTION WITH ACOUSTIC CENSUS: FALL - WINTER

| | | DARLINGTON GS | | | | PORT DARLINGTON | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | INSHORE | | OFFSHORE | | INSHORE | | OFFSHORE | |
| | | No | % | No | % | No | % | No | % |
| DAY | Alewife | 1 | 9 | | | | | | |
| | Smelt | 1 | 9 | 1 | 50 | | | 2 | 66 |
| | W. Sucker | 1 | 9 | | | | | 1 | 33 |
| | R. Whitefish | 8 | 73 | 1 | 50 | | | | |
| | TOTAL | 11 | | 2 | | | | 3 | |
| NIGHT | White Sucker | 1 | 33 | | | | | | |
| | Shiner | 2 | | 0 | | | | | |
| | TOTAL | 3 | | | | | | | |

numbers of alewife entangled in gill net mesh over 6 cm in 1977 suggested that they would have been the numerically dominant species had 3.8 cm (1-1/2") mesh panels been included.

A significant portion of total fish density in late fall was attributed to small amplitude echoes scattered off bottom, representing small pelagic fish such as alewife (see particularly the 12-16 m bottom depth range in Figure 3). Also making a significant contribution to fish density were White Suckers (Catostomus commersoni) which comprised 18% of the 1978 catch and 28% of the 1977 catch.

Yearly Average Distribution

Fish densities on the four temporal periods (Figures 2 and 3) were averaged to obtain a yearly vertical fish distribution (Figure 4a). This presentation tends to reflect the distribution of alewife and smelt during their period of peak abundance in the nearshore area. At both the West Embankment and Raby Head highest average densities generally occurred within 2 m of bottom. However, near-bottom densities decreased substantially beyond the 12 m contour at both sites. Lesser numbers of fish were encountered throughout the water column. The lowest density (<10 fish/10,000 $m^3$) was encountered in midwater at bottom depths over 20 m.

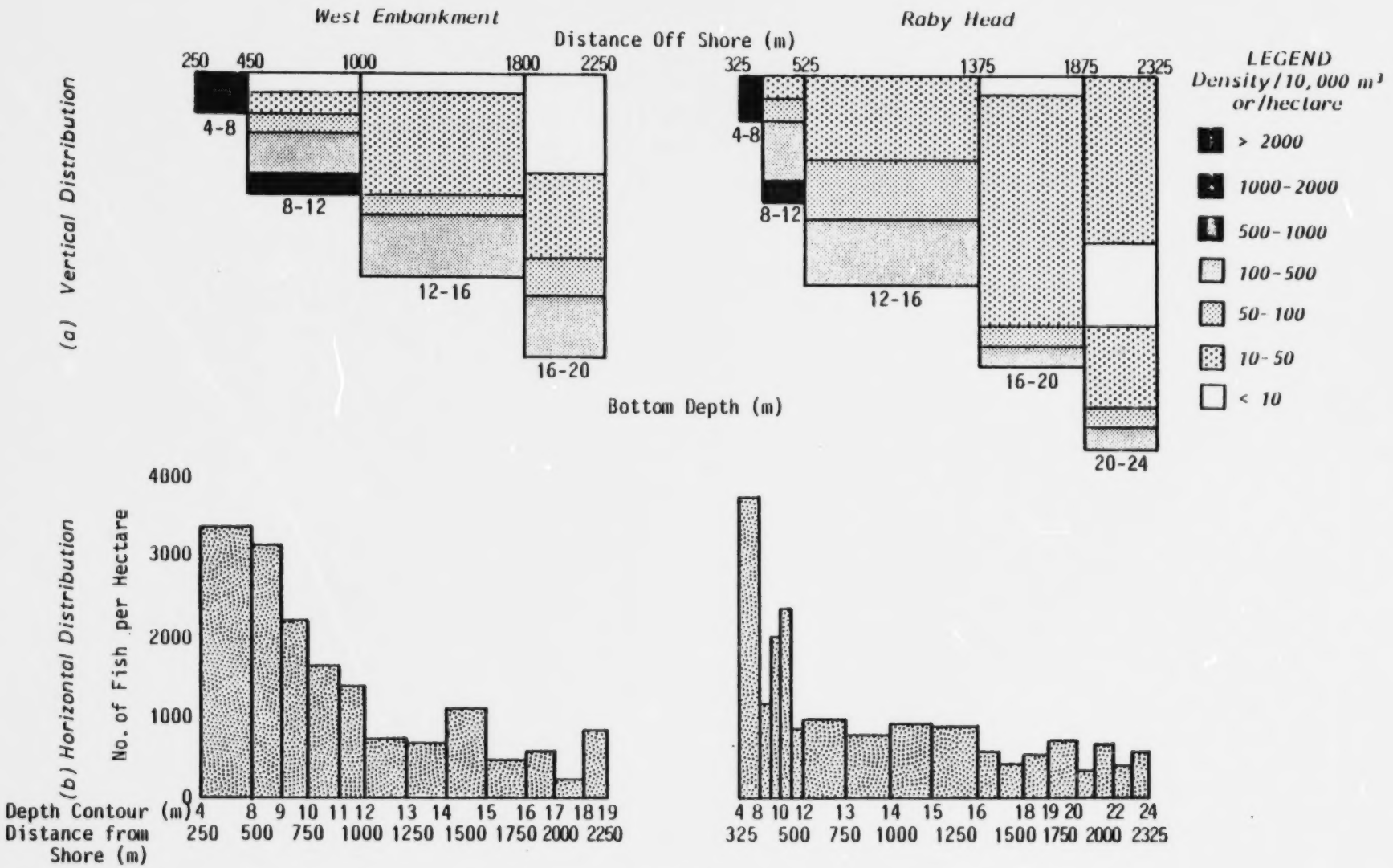



FIGURE 4

FISH DENSITY IN THE VICINITY OF DARLINGTON GS; YEARLY AVERAGE

150168 RD

To define the onshore-offshore density gradient more precisely, fish densities/hectare were averaged over 1 m contour intervals (Figure 4b). At the West Embankment a relatively smooth decrease in density from approximately 3000 to less than 1000 fish/hectare was observed between the 8 m and 13 m contours. Beyond 13 m, densities remained relatively uniform. Off Raby Head fish densities fell below 1000 fish/hectare beyond the 11 m contour. The decrease to that point was irregular, due to the relatively steep bottom slope and therefore, the restricted area sampled. Densities were moderate to 16 m, then decreased again. The distance from shore at which densities lower than 1000 fish/hectare were encountered was approximately 1 km for the West Embankment and 0.5 km for Raby Head.

Potential for Fish Losses at Submerged Intakes

The rate at which fish are entrained by a submerged intake is essentially a product of their frequency of contact with the intake's capture field and their vulnerability to capture. The frequency of contact is in turn determined by abundance and rate of movement. Abundance has been estimated acoustically, and its spatial and temporal variation described. Variation in the other factors affecting entrapment rate involve complex, species-specific behavioural and physiological responses to the environment. Such factors are either constant (ie intake characteristics) or vary in a more or less consistent temporal fashion.

Factors which vary temporally include two which were implicated by James F. McLaren (1979) as major contributors to the rate of entrapment. These were the rate of movement and environmental factors, principally storm-induced turbidity, which increased the probability of capture by eliminating visual cues that allowed the fish to take evasive action. The degree of movement may vary seasonally, as in spawning migrations in spring, or diurnally, as sometimes seen in onshore movements of alewife at dusk. Similarly, the frequency of storms varies seasonally, and the amount of light penetrating to intake depth varies both seasonally and diurnally.

Unfortunately, while differences can be pointed out, they cannot readily be quantified. Here two indicators of potential fish entrapment relative to location are suggested:

1) the yearly average density distribution, and

2) the density distribution during the period of probable greatest risk, considering overall abundance and biotic factors.

The temporal period of greatest risk for entrapment is felt to be spring-summer/night. This is based on the relatively high overall densities, together with an assumed increase in contact with the intake field due to inshore-offshore movements and an increased vulnerability to capture at low light levels.

Density distribution for spring-summer night (Figure 2) and the yearly average (Figure 5) both strongly suggest that the risk of fish entrapment at a conventional submerged intake is greatest at bottom depths of less than 8-9 m, and decreases with increasing depth. The risk of entrapment appeared similar at the two areas at depths of less than 8 m, but may have been somewhat less at Raby Head at greater depths. The risk of entrapment of rainbow smelt probably does not decrease with depth to the same extent as the overall risk, which reflects primarily the distribution of alewife. The experience at Pickering GS (Ontario Hydro Research Division Report No 80-226-K) and catch records in the vicinity of Darlington indicate that these are the only species likely to be at risk in substantial numbers.

SUMMARY

1. Acoustic fish census data from fifteen 2 km x 2 km nearshore grid samples collected in the vicinity of Darlington GS and Port Darlington during 1978 and 1979 were re-examined to provide improved vertical resolution referenced to the bottom and a yearly average density distribution.

2. From May to October mean fish densities varied considerably but always exceeded 500 fish/hectare (571-5424). In November and December mean densities declined to less than 400 fish/hectare. In spring and summer fish were concentrated near bottom by day and by night distributed throughout the water column or, in the deepest waters, in bottom and midwater layers. Near-bottom densities declined with distance from shore beyond 8 m bottom depth. Off the West Embankment, within 1 m of bottom average density decreased from 1500 to 250 fish/10,000 $m^3$ from 8-12 to 12-16 m. The distance from shore at which density decreased below 1000 fish/hectare was 1 km off the West Embankment but only 0.5 km off Raby Head.

3. The species contributing almost all of the acoustically observed fish were alewife and rainbow smelt, and these face the greatest potential risk for intake entrapment at Darlington GS. The risk of entrapment appears to be greatest at depths of less than 8-9 m where it is similar off the West Embankment and Raby Head. Beyond 8 m, the risk of entrapment, particularly of alewife, appears to decline with increasing depth, and may be somewhat lower off Raby Head than the West Embankment.

Approved:

D. Harrison
Manager
Chemical Research Department

Submitted:

H. Balesic
Biologist - Fish Behaviour
Biological Research Section

HB:rdm

## REFERENCES


James F. MacLaren Ltd.1979. Fish Entrapment as it Relates to Their Densities and Movements Around Cooling Water Intake Structures. Report to Ontario Hydro. J.R. Foster. Volume 1.

Ontario Hydro Research Division Report No 78-48-K. Whitefish Spawning Study, Darlington GS - 1977. W.E. Dunford. March 21, 1978.

Ontario Hydro Research Division Report 79-363-K. Fish Distribution and Abundance along the North Shore of Lake Ontario. Summer, Early Fall, 1978 Intake Location Study Interim Report. H. Balesic, Aug 19, 1979.

Ontario Hydro Research Division Report 79-434-K. Fish Distribution and Abundance along the North Shore of Lake Ontario - Fall, 1978 Intake Location Study Interim Report. H. Balesic, October 18, 1979.

Ontario Hydro Research Division Report 80-197-K. Fish Distribution and Abundance along the North Shore of Lake Ontario. Spring 1979 Intake Location Study Interim Report. H. Balesic. July 3, 1980.

Ontario Hydro Research Division Report No 80-226-K. Pickering GS "A" Three Year Post-Operational Summary Report, 1974-1976. J. Kwik and H. Balesic, Aug 18, 1980.

Ontario Hydro Research Division Report No 80-387-K. Biological Studies at Darlington 'B' Site, 1978. Vol 1. G.L. Vascotto (Co-ordinator), Jan 23, 1981.

## APPENDIX 1

## DERIVATION OF DENSITY ESTIMATES IN 1 M INCREMENTS ABOVE BOTTOM

The procedure for deriving density estimates in 1 m increments above bottom is illustrated by the accompanying table (a) and graph (b), which represent the derivations for the spring-summer period, West Embankment, for the 8-12 m bottom depth range.

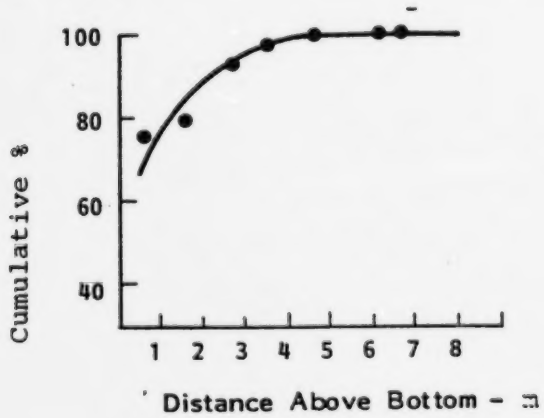
(a) Sample Derivation of Average Densities for Bottom Depths of 8-12 m

| | Bottom Depth Ranges - M | | | |
|---|---|---|---|---|
| | 8.1-9 | 9.1-10 | 10.1-11 | 11.1-12 |
| For May 23 Sample: | | | | |
| No of Intervals | 3 | 4 | 4 | 5 |
| Mean No/10,000 $m^3$ | | | | |
| - 4-8 m | 1,269 | 988 | 90 | 157 |
| - 8-12 m | 32,250 | 8,165 | 4,186 | 3,218 |
| For Season: | | | | |
| No of Samples - 4 | | | | |
| Mean No/10,000 $m^3$ | | | | |
| - 4-8 m | 694 | 285 | 58 | 43 |
| - 8-12 m | 9,250 | 2,619 | 1,371 | 1,052 |
| Mean Bottom Depth | 8.6 | 9.6 | 10.6 | 11.5 |
| Density/10,000 $m^3$ | | | | |
| - 4-8 m | 2,776 | 1,141 | 233 | 172 |
| - 8-12 m | 5,827 | 4,298 | 3,588 | 3,672 |
| Total Density/ 10,000 $m^3$ | 8,603 | 5,437 | 3,821 | 3,843 |

During the period, 4 acoustic samples were collected, one of which was May 23 (2). On May 23, four data-logging intervals had bottom depths from 9.1-10 m. The mean density in the 8-12 m depth shell for those intervals was 8165 fish/10,000 $m^3$. This value was averaged with 8-12 m depth shell/9.1-10 m bottom depth density means from the three other samples in the spring-summer period, to give a seasonal mean of 2619 fish/10,000 $m^3$.

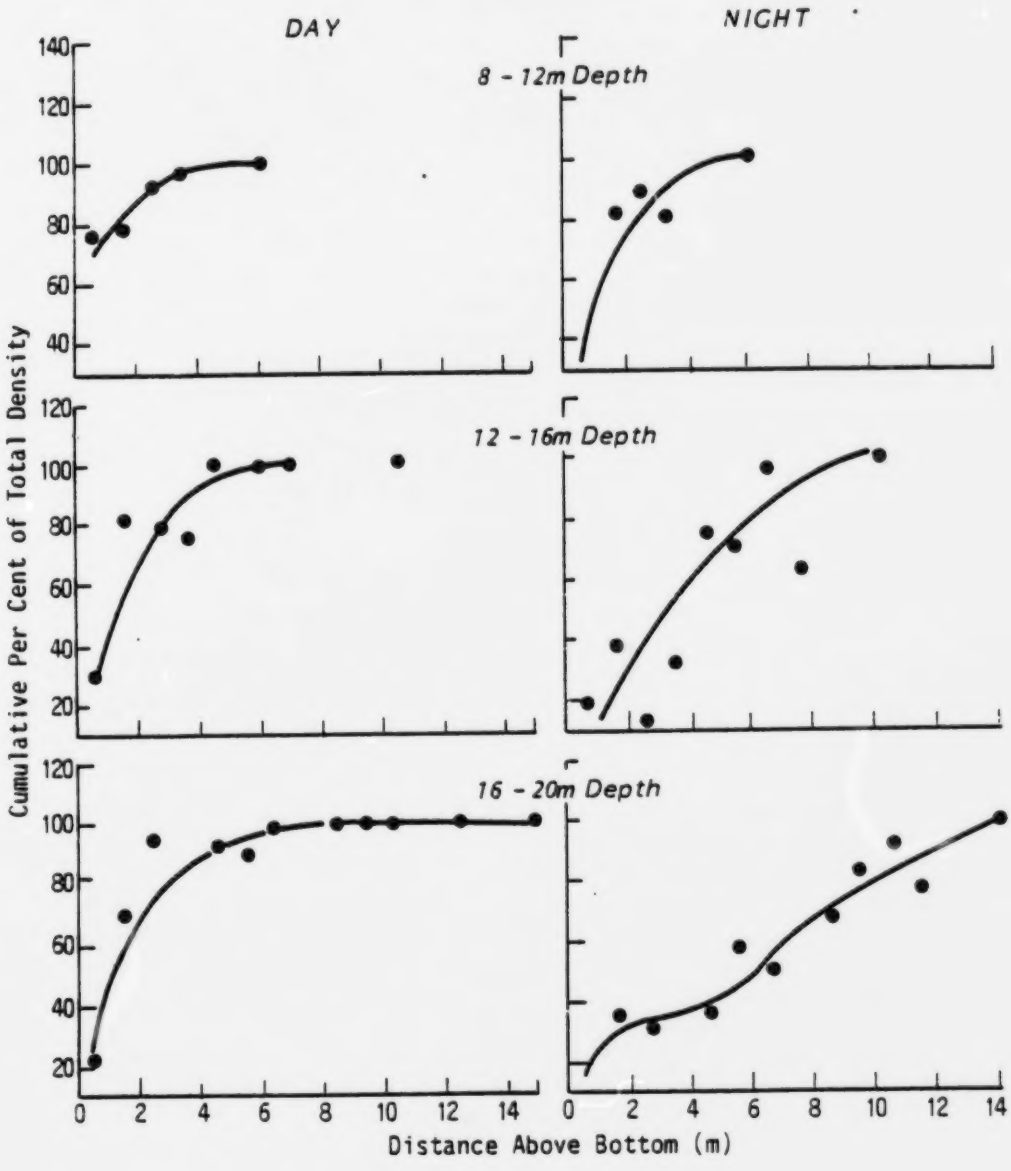
The average bottom depth in the group of data-logging intervals was 9.64 m. The average thickness of the 8-12 m depth shell was therefore 1.64 m (9.64-8). The density/hectare for the 8-12 m depth range above was 1.64 x 2619 = 4298 fish/hectare, which was 79% of the total density/hectare of 5437 fish. Thus 79% of the fish were observed in the first 1.64 m above bottom. The per cent of fish observed at varying distance from bottom ranging from 0.6 m to 3.5 m was plotted and a curve fitted by eye (b). The per cent of average total density (5426/hectare) in the water column from 1 m increments above the bottom was estimated from the curve, and the density/10,000 $m^3$ calculated. For example, an estimated 12% of the fish (88-76%) observed between 1 and 2 m of bottom represented 0.12 x(5426 = 651 fish/10,000 $m^3$. All plots used for density estimation are given in Appendix 2.

(b) Plot of Cumulative Contribution to Total Density from (a)

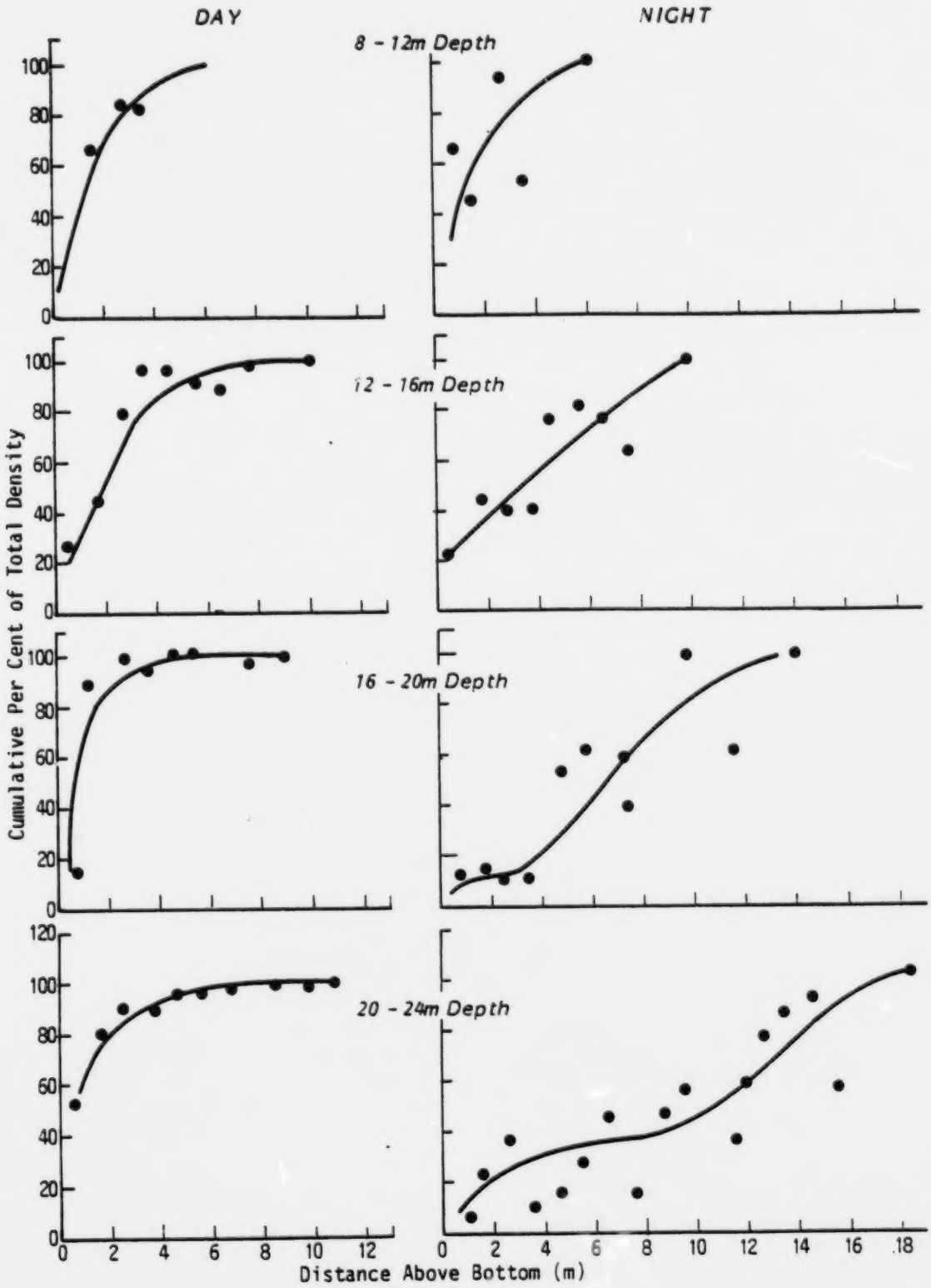



It should be noted that this process of averaging introduced weighting of unequally represented 1 m bottom depth ranges, and that the average total density/hectare was therefore not identical to the mean of all intervals within the 4 m bottom depth range. For example, the mean density for all intervals at 8.1-12 m bottom depth (corresponding to the weighted average of 5426/hectare) was 4140 fish/hectare.

APPENDIX 1. PLOTS OF COMULATIVE CONTRIBUTION TO TOTAL FISH DENSITY FOR DERIVATION OF DENSITY IN 1M INCREMENTS ABOVE BOTTOM.

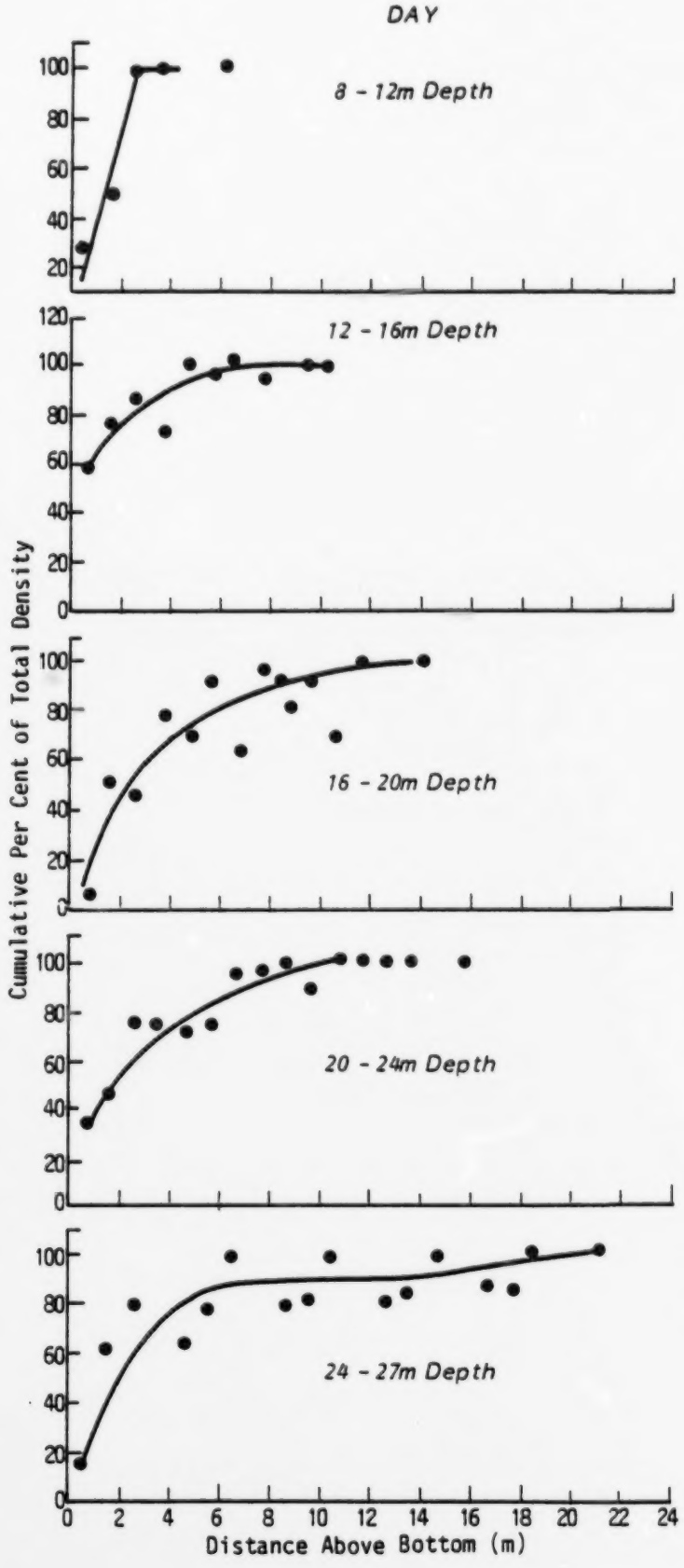



(A) WEST EMBANKMENT - SPRING-SUMMER

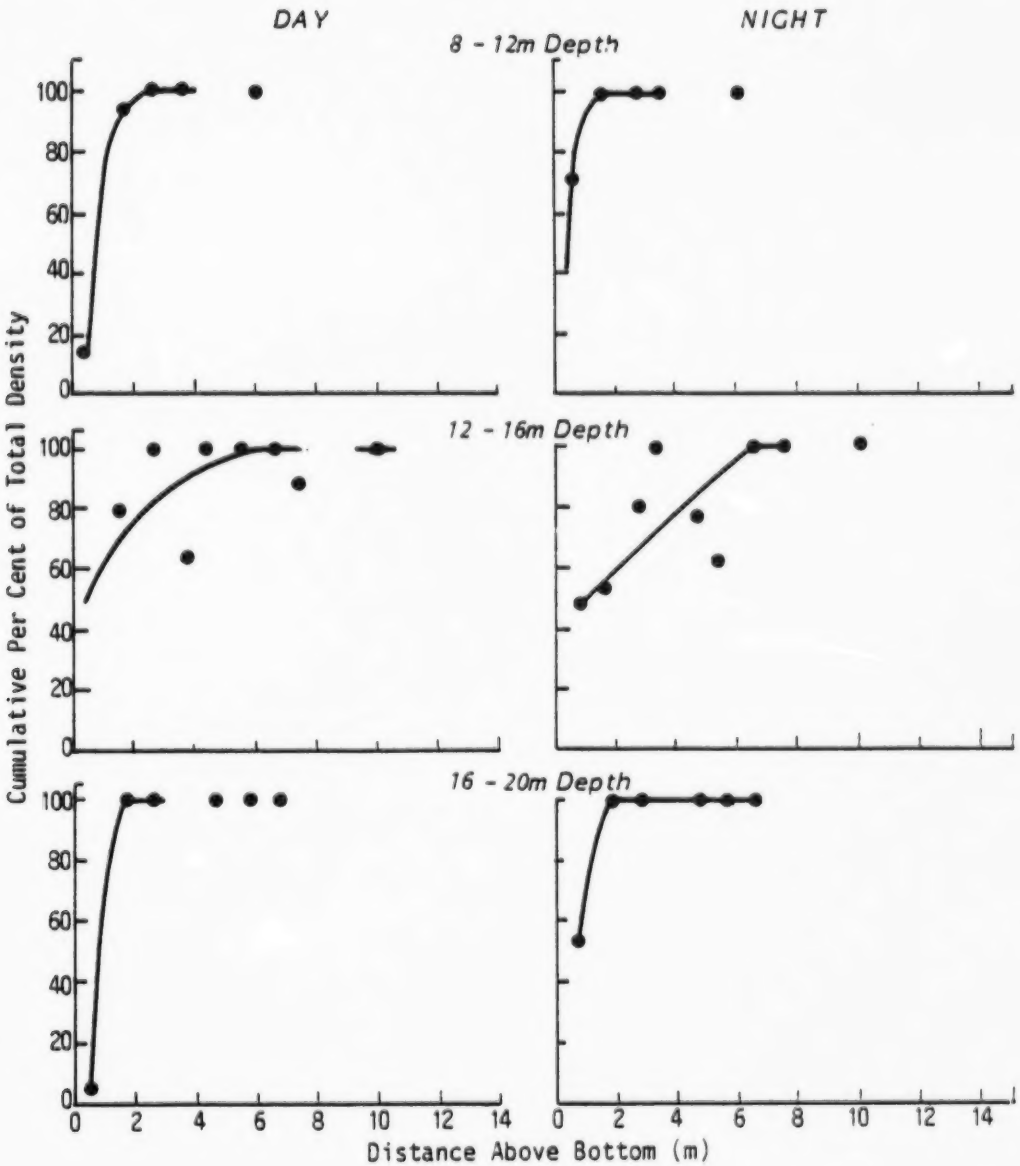



(E) RABY HEAD - SPRING-SUMMER

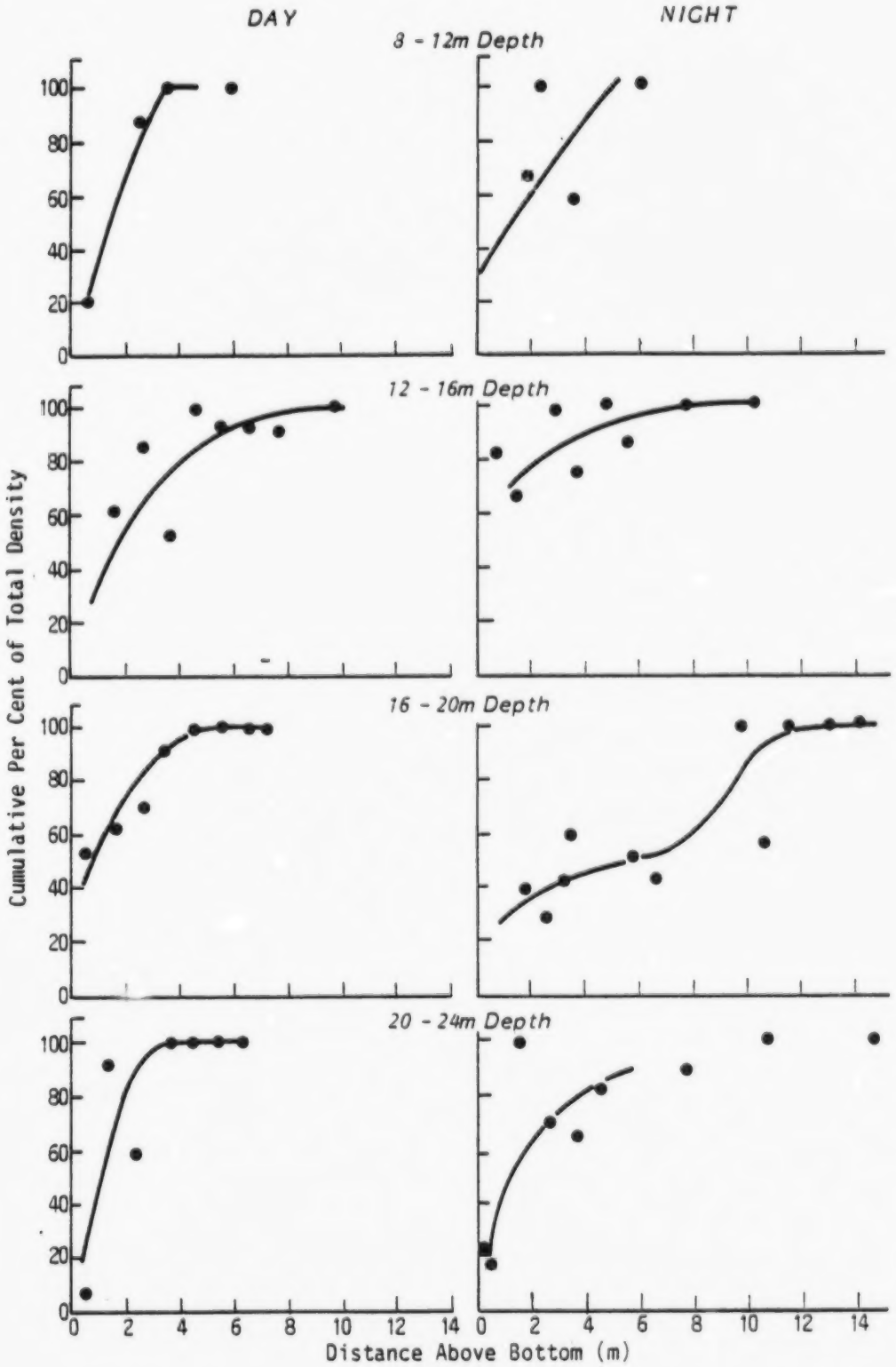
150163 RD




(C) PORT DARLINGTON - SPRING-SUMMER




(D) WEST EMBRANKMENT - FALL-WINTER




(E) RABY HEAD - FALL-WINTER

150160 RD

## APPENDIX 3 FISH DENSITIES

## RELATIVE TO BOTTOM NEAR DARLINGTON GS

### (a) WEST EMBANKMENT

| | | SPRING - SUMMER | | | | FALL - WINTER | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | BOTTOM DEPTH RANGE (M) | | | | BOTTOM DEPTH RANGE (M) | | | |
| | | 4-8 | 8-12 | 12-16 | 16-20 | 4-8 | 8-12 | 12-16 | 16-20 |
| DAY | AVERAGE DISTANCE SAMPLED (M) | 240 | 570 | 834 | 349 | | | | |
| | AVERAGE DENSITY/HECTARE | 7152 | 5426 | 1427 | 1859 | 2537 | 545 | 140 | 121 |
| | NO OF INTERVALS* | 29 | 67 | 98 | 51 | 13 | 45 | 48 | 18 |
| | ESTIMATED DENSITIES/10,000M³ AT DISTANCE FROM BOTTOM - M 1 | - | 4123 | 624 | 929 | - | 382 | 84 | 85 |
| | 2 | 2455 | 651 | 314 | 372 | 855 | 150 | 21 | 36 |
| | 3 | - | 434 | 256 | 186 | - | 13 | 14 | 0 |
| | 4 | | 109 | 129 | 86 | | 0 | 11 | 0 |
| | 5 | | 109 | 57 | 74 | | 0 | 7 | |
| | 6 | | 0 | 43 | 74 | | | 4 | 0 |
| | 7 | | | 0 | 37 | | | 0 | 0 |
| | 8 | | | 0 | 0 | | | 0 | |
| | 9 | | | | 0 | | | | |
| | 10 | | | | | | | | |
| | 11 | | | | | | | | |
| | 12 | | | | | | | | |
| NIGHT | AVERAGE DENSITY/HECTARE | 2245 | 1777.7 | 1160.1 | 637 | 1211 | 547 | 201 | 124 |
| | NO OF INTERVALS* | 15 | 45 | 60 | 48 | 7 | 22 | 21 | 12 |
| | ESTIMATED DENSITIES/10,000M³ AT DISTANCE FROM BOTTOM-M 1 | | 889 | 174 | 159 | - | 491 | 100 | 106 |
| | 2 | 756 | 444 | 174 | 51 | 385 | 55 | 18 | 18 |
| | 3 | - | 213 | 174 | 13 | - | 0 | 18 | 0 |
| | 4 | | 147 | 174 | 13 | | | 18 | 0 |
| | 5 | | 53 | 116 | 25 | | | 18 | |
| | 6 | | 36 | 91 | 51 | | | 18 | |
| | 7 | | | 87 | 70 | | | 12 | |
| | 8 | | | 75 | 44 | | | 0 | |
| | 9 | | | 69 | 44 | | | 0 | |
| | 10 | | | 23 | 32 | | | | |
| | 11 | | | | 32 | | | | |
| | 12 | | | | 32 | | | | |
| | 13 | | | | 32 | | | | |
| | 14 | | | | 32 | | | | |
| YEARLY AVERAGE (DAY & NIGHT) | AVERAGE DENSITY/HECTARE | 3285 | 2074 | 732 | 685 | | | | |
| | ESTIMATED DENSITIES/10,000M³ AT DISTANCE FROM BOTTOM-M 1 | - | 1472 | 245 | 320 | | | | |
| | 2 | 1113 | 325 | 132 | 119 | | | | |
| | 3 | - | 165 | 116 | 50 | | | | |
| | 4 | | 63 | 83 | 50 | | | | |
| | 5 | | 40 | 49 | 25 | | | | |
| | 6 | | 9 | 35 | 36 | | | | |
| | 7 | | | 25 | 20 | | | | |
| | 8 | | | 19 | 11 | | | | |
| | 9 | | | 17 | 11 | | | | |
| | 10 | | | 6 | 8 | | | | |
| | 11 | | | | 8 | | | | |
| | 12 | | | | 8 | | | | |
| | 13 | | | | 8 | | | | |
| | 14 | | | | 8 | | | | |

* ACOUSTIC DATA-LOGGING INTERVAL OF 30 SECONDS (APPROXIMATELY 100 M OF TRANSECT)

## APPENDIX 3(b) - RABY HEAD

| | | SPRING-SUMMER | | | | | FALL-WINTER | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | BOTTOM DEPTH RANGE (M) | | | | | BOTTOM DEPTH RANGE (M) | | | | |
| | | 4-8 | 8-12 | 12-16 | 16-20 | 20-24 | 4-8 | 8-12 | 12-16 | 16-20 | 20-24 |
| DAY | AVERAGE DISTANCE SAMPLED (M) | 100 | 200 | 950 | 450 | 400 | | | | | |
| | AVERAGE DENSITY/HECTARE | 13923 | 4039 | 1962 | 926 | 1060 | 602 | 295 | 266 | 78 | 53 |
| | NO OF INTERVALS | 11 | 24 | 110 | 59 | 43 | 4 | 22 | 49 | 30 | 25 |
| | ESTIMATED DENSITIES/10,000 $M^3$ AT DISTANCE FROM BOTTOM - 1 | | 1697 | 667 | 602 | 678 | | 106 | 98 | 45 | 23 |
| | 2 | 4785 | 1050 | 392 | 213 | 180 | 219 | 89 | 51 | 13 | 20 |
| | 3 | | 566 | 373 | 65 | 35 | | 71 | 35 | 10 | 7 |
| | 4 | | 363 | 255 | 46 | 53 | | 29 | 27 | 7 | 2 |
| | 5 | | 202 | 118 | 0 | 32 | | 0 | 21 | 4 | 0 |
| | 6 | | 121 | 98 | 0 | 22 | | 0 | 16 | 0 | 0 |
| | 7 | | | 39 | | 11 | | | 11 | 0 | |
| | 8 | | | 20 | | 0 | | | 5 | | |
| | 9 | | | 0 | | 0 | | | 3 | | |
| | 10 | | | 0 | | 0 | | | 3 | | |
| NIGHT | AVERAGE DENSITY/HECTARE | 350 | 1574 | 1173 | 1049 | 1044 | 254 | 562 | 189 | 177 | 89 |
| | NO OF INTERVALS | 1 | 17 | 60 | 35 | 32 | 3 | 14 | 18 | 13 | 15 |
| | ESTIMATED DENSITIES/10,000 $M^3$ AT DISTANCE FROM BOTTOM - 1 | | 629 | 328 | 125 | 125 | | 253 | 132 | 53 | 43 |
| | 2 | 100 | 393 | 106 | 0 | 94 | 84 | 90 | 15 | 13 | 16 |
| | 3 | | 236 | 106 | 21 | 52 | | 78 | 11 | 9 | 9 |
| | 4 | | 157 | 106 | 84 | 31 | | 78 | 9 | 7 | 5 |
| | 5 | | 110 | 106 | 105 | 31 | | 67 | 8 | 3 | 4 |
| | 6 | | 47 | 106 | 125 | 21 | | 0 | 6 | 3 | 3 |
| | 7 | | | 94 | 115 | 21 | | | 4 | 9 | 4 |
| | 8 | | | 82 | 115 | 21 | | | 2 | 9 | 2 |
| | 9 | | | 82 | 115 | 31 | | | 2 | 21 | 2 |
| | 10 | | | 70 | 94 | 42 | | | 0 | 32 | 2 |
| | 11 | | | | 63 | 52 | | | | 14 | 0 |
| | 12 | | | | 52 | 94 | | | | 5 | 0 |
| | 13 | | | | 42 | 94 | | | | 70 | 3 |
| | 14 | | | | 21 | 94 | | | | 0 | |
| | 15 | | | | | 94 | | | | | |
| | 16 | | | | | 73 | | | | | |
| | 17 | | | | | 52 | | | | | |
| | 18 | | | | | 42 | | | | | |
| YEARLY AVERAGE (DAY & NIGHT) | AVERAGE DENSITY/HECTARE | 3782 | 1545 | 897 | 557 | 561 | | | | | |
| | ESTIMATED DENSITIES/10,000 $M^3$ AT DISTANCE FROM BOTTOM - 1 | | 671 | 306 | 206 | 217 | | | | | |
| | 2 | 1297 | 405 | 141 | 60 | 77 | | | | | |
| | 3 | | 237 | 131 | 26 | 38 | | | | | |
| | 4 | | 157 | 99 | 35 | 30 | | | | | |
| | 5 | | 95 | 63 | 28 | 17 | | | | | |
| | 6 | | 42 | 56 | 38 | 11 | | | | | |
| | 7 | | | 37 | 39 | 9 | | | | | |
| | 8 | | | 27 | 39 | 6 | | | | | |
| | 9 | | | 22 | 36 | 6 | | | | | |
| | 10 | | | 18 | 24 | 5 | | | | | |
| | 11 | | | | 14 | 11 | | | | | |
| | 12 | | | | 13 | 158 | | | | | |
| | 13 | | | | 11 | 47 | | | | | |
| | 14 | | | | 5 | 36 | | | | | |
| | 15 | | | | | 20 | | | | | |
| | 16 | | | | | 13 | | | | | |
| | 17 | | | | | 16 | | | | | |

APPENDIX 3(c) PORT DARLINGTON-DAY ONLY

| | SPRING - SUMMER | | | | | | FALL - WINTER | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BOTTOM DEPTH RANGE (M) | | | | | | BOTTOM DEPTH RANGE (M) | | | | | |
| | 4-8 | 8-12 | 12-16 | 16-20 | 20-24 | 24-28 | 4-8 | 8-12 | 12-16 | 16-20 | 20-24 | 24-28 |
| AVERAGE DISTANCE SAMPLED(M) | | | | | | | | | | | | |
| AVERAGE DENSITY/HECTARE | | | | | | | | | | | | |
| NO OF INTERVALS* | 4145 | 1044 | 1662 | 2835 | 1175 | 930 | 1015 | 307 | 27 | 35 | 219 | 148 |
| ESTIMATED DENSITIES/10,000M$^2$ | | | | | | | | | | | | |
| LM | - | 397 | 1097 | 709 | 5447 | 2-9 | - | 255 | 22 | 28 | 219 | 148 |
| 2 | 1346 | 397 | 150 | 623 | 188 | 205 | 440 | 52 | 5 | 7 | 67 | 0 |
| 3 | - | 251 | 133 | 340 | 117 | 130 | - | 0 | 0 | 0 | 0 | 0 |
| 4 | | 0 | 116 | 283 | 105 | 93 | | 0 | 0 | 0 | 0 | |
| 5 | | 0 | 83 | 198 | 82 | 65 | | | | | | |
| 6 | | | 33 | 170 | 71 | 28 | | | | | | |
| 7 | | | 16 | 142 | 59 | 9 | | | | | | |
| 8 | | | 16 | 113 | 47 | 0 | | | | | | |
| 9 | | | 0 | 85 | 35 | 0 | | | | | | |
| 10 | | | 0 | 57 | 21 | 5 | | | | | | |
| 11 | | | | 57 | 12 | 5 | | | | | | |
| 12 | | | | 28 | 0 | 5 | | | | | | |
| 13 | | | | 28 | 0 | 5 | | | | | | |
| 14 | | | | 0 | | 9 | | | | | | |
| 15 | | | | | | 9 | | | | | | |
| 16 | | | | | | 0 | | | | | | |
| 17 | | | | | | 19 | | | | | | |
| 18 | | | | | | 19 | | | | | | |
| 19 | | | | | | 19 | | | | | | |
| 20 | | | | | | 9 | | | | | | |
| 21 | | | | | | 9 | | | | | | |

* ACOUSTIC DATA LOGGING INTERVALS (EQUAL TO APPROXIMATELY 100 M OF TRANSECT)